Acta Aquatica Turcica
E-ISSN: 2651-5474 16(4), 525-534 (2020) DOI: https://doi.org/10.22392/actaquatr.735868

Spawning Period and Size at Maturity of the Thornback Ray, *Raja clavata* (Linnaeus, 1758), (Elasmobranchii: Rajidae) in the Black Sea

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Research Article

Received 11 May 2020; Accepted 14 September 2020; Release date 01 December 2020.

How to Cite: Bilgin, S., & Onay, H. (2020). Spawning period and size at maturity of the thornback ray, *Raja clavata* (Linnaeus, 1758), (Elasmobranchii: Rajidae) in the Black Sea. *Acta Aquatica Turcica, 16*(4), 525-534. https://doi.org/10.22392/actaquatr.735868

Abstract

To describe the spawning period, size at maturity (L_m), reproductive load (L_m/L_{max}), length at maximum yield per recruit (L_{opt}) of thornback ray (*Raja clavata*); and to assess the differences in these parameters from other populations, a total of 18 months samplings were conducted between February 2011 and December 2013 in the southeast Black Sea. A total of 265 (160 females and 105 males) specimens of thornback ray were examined. The mean total length (L) of females was significantly greater than the mean total length of males (p<0.05). The GSI analysis revealed that thornback ray showed reproductive activities throughout the year. The L_m was estimated as 75.44 cm for females and 71.71 cm for males. The L_{opt} was estimated from the empirical relationships between the L_{opt} and L_m, and it was larger than L_m for both sexes.

Keywords: Life history, reproduction biology, maturation, fisheries management

Karadeniz'de Vatoz Balığının, *Raja clavata* (Linnaeus, 1758) (Elasmobranchii: Rajidae) Üreme Zamanı ve Cinsi Olgunluk Boyu

Özet

Karadeniz'de vatoz balığının üreme zamanı, cinsi olgunluk boyu (L_m), üreme yükü (L_m/L_{max}) ve yeni birey katılım başına maksimum ürün boyunu (L_{opt}) belirlemek ve bu parametreleri diğer popülasyonlarda yapılan çalışma sonuçlarıyla kıyaslama için Ocak 2011 ve Aralık 2013 arasında 18 ay örnekleme yapılmıştır. Toplam 265 birey (160 dişi, 105 erkek) incelenmiştir. Dişilerin ortalama toplam boyu erkeklerden istatistiksel olarak büyük hesaplanmıştır (p<0,05). GSI değerleri üreme aktivitesinin yıl boyu devam ettiğini göstermiştir. L_m dişiler için 75,44 cm, erkekler için 71,71 cm olarak hesaplanmıştır. Her ikicinsiyet için tespit edilen L_m değeri L_{opt} değerinden büyük bulunmuştur ($L_m > L_{opt}$).

Anahtar kelimeler: Hayat döngüsü, üreme biyolojisi, olgunlaşma, balıkçılık yönetimi

INTRODUCTION

The thornback ray, *Raja clavata* (Linnaeus, 1758), is a widely distributed skate in Eastern Atlantic and Southwest Indian Ocean: Iceland to Madagascar, including the Mediterranean and Black Sea (Froese and Pauly, 2019). It is most abundant in 10-60 m of water off coastal areas and inhabits a variety of substrates, including mud, sand, shingle, gravel, and rocky areas (Froese and Pauly, 2019). It was reported between 10 and 300 m in the North Sea (Walker et al., 1997) and between 300 and 577 m in the Ionian Sea (Mytilineou et al., 2005). In the North Sea, adults move to offshore, relatively deep water (up to 30 m) in the winter months (December to March) and returned to shallow, inshore waters (up to 10 m) in the summer months (Walker et al., 1997). In the Black Sea, it habits mainly between 20 and 40 m (Saglam and Ak, 2011), up to 120 m deep (Demirhan et al., 2005) and feeds on preferably crustaceans such as shrimp and crab species and fish as whiting, red mullet, and goby (Demirhan et al., 2005; Saglam and Bascinar, 2008). Ray species are among the top predators in the marine environment, affecting the populations of fish and invertebrates at lower trophic levels (Ellis et al. 1996). Moreover, rays represent an important constituent of the multispecies demersal landings caught especially by demersal trawling gear. Rays are also an important bycatch in the gill and tangle net fisheries in Turkey. In some areas, a large part may be discarded, with only the largest ones being landed for consumption on the European market (Fahy, 1989). However, in some demersal fisheries (e.g. in the Bristol Channel, Irish Sea, and the North Sea) immature fish are also marketable (Fahy, 1989; Walker, 1999).

Till the early 1990s, the whole yield of thornback ray was processed into minced meat for feeding of poultry and other domestic animals in Ukraine (Shlyakhov and Charova, 2003). After the 2000s, there has been observed people's demand for thornback ray as human food in the Black Sea countries. Moreover, some studies were carried out on the processing of this fish and suggested that it can be a good alternative for surimi production due to their white meat and low-fat content (Turan and Sönmez, 2009). In recent years, there is no evidence that thornback ray is a target species for consumption. They are only accidentally caught during trawl and turbot gill fisheries and released back into the Black Sea completely as live and/or dead (personal observation).

Reproduction biology parameters such as spawning season, size at maturity, fecundity, and others (e.g. reproductive load, etc.) are key population input parameters in the assessment and management of exploited and/or unexploited fish stocks (Tsikliras et al., 2010; Tsikliras and Stergiou, 2014). These reproduction biology parameters of thornback ray were previously reported from different geographic regions such as British water (Steven, 1934; Ryland and Ajayi, 1984; McCully et al., 2012), Irish sea (Nottage and Perkins, 1983; Gallagher et al., 2005; Whittamore and McCarthy, 2005), Adriatic sea (KrstulovićŠifner et al., 2009; Jardas, 1973), Portuguese coast of Atlantic (Serra-Pereira et al., 2011), Mediterranean Sea of Tunisia and France coast (Kadri et al., 2014; Capapé et al., 2007). Moreover, previous research into thornback ray reproduction has been rather fragmentary in the Black Sea. Only two studies have been conducted on the subject on the Black Sea coast of Turkey so far (Demirhan et al., 2005; Saglam and Ak, 2011). Any changes in the ecosystem and environmental conditions together with global warming may cause a serious impact on the fish population as possible influence spawning period, maturity, etc. The maturity of fish could vary among year classes of the same stock even though growth remained constant from year to year and the variation could be attributed to the temperature regime that fish were exposed to during the early life stage (Alm, 1959). Furthermore, fluctuations in both ambient water temperature and the abundance of stock between years are considered as factors affecting sexual maturity (O'Brien, 1999). For better understanding the possible changes in thornback ray population, frequent monitoring surveys are very essential. The present study contains current results, which will allow for a better understanding of this fish population in the south-eastern Black Sea since the species has been declared as a near threatened (NT) species in the IUCN red list of threatened species (Ellis, 2016).

The objective of the present study was to contribute with information on the spawning period, provide first findings of length at maximum yield per recruit (L_{opt}) and reproductive load (L_m/L_{max}) of this species, also to present some detailed estimation on the size at maturity (L_m) necessary for the introduction of suitable management plans for thornback ray in the Anatolian coast of the Black Sea and to assess the differences in these parameters in other populations of the different geographical region.

MATERIALS and METHODS

Study area and sampling

Samples of thornback ray (*R. clavata*) were collected on the Rize province coasts of the southeastern Black Sea (Fig. 1) using turbot gill net with 360 mm stretched mesh size and beam trawl with 15 mm cod-end stretched mesh size. Although commercial turbot gill net is banned in the Turkish Black Sea coast between May and June, and also beam trawl during the year, sampling surveys were conducted with a special permit for turbot fishery to determine the interaction between turbot fishery and cetaceans, and to determine crab population dynamics. Since monthly sampling was not carried out regularly, a total of 18 sampling months (In 2011: February, March, April, May, June, August; In 2012: April, May, June, July and in 2013: January, February, March, April, May, October, November, and December) were seasonally evaluated to determine spawning period. Seasons were grouped as winter (December - February), spring (March-May), summer (June - August), and autumn (September - November). For each specimens, total length (*TL*) was recorded to the nearest 1 mm on the linear axis as the distance between the tip of the snout to the end of the tail. Total wet weight (*W*) and gonad weight (W_g) were recorded to the nearest 0.1 g.

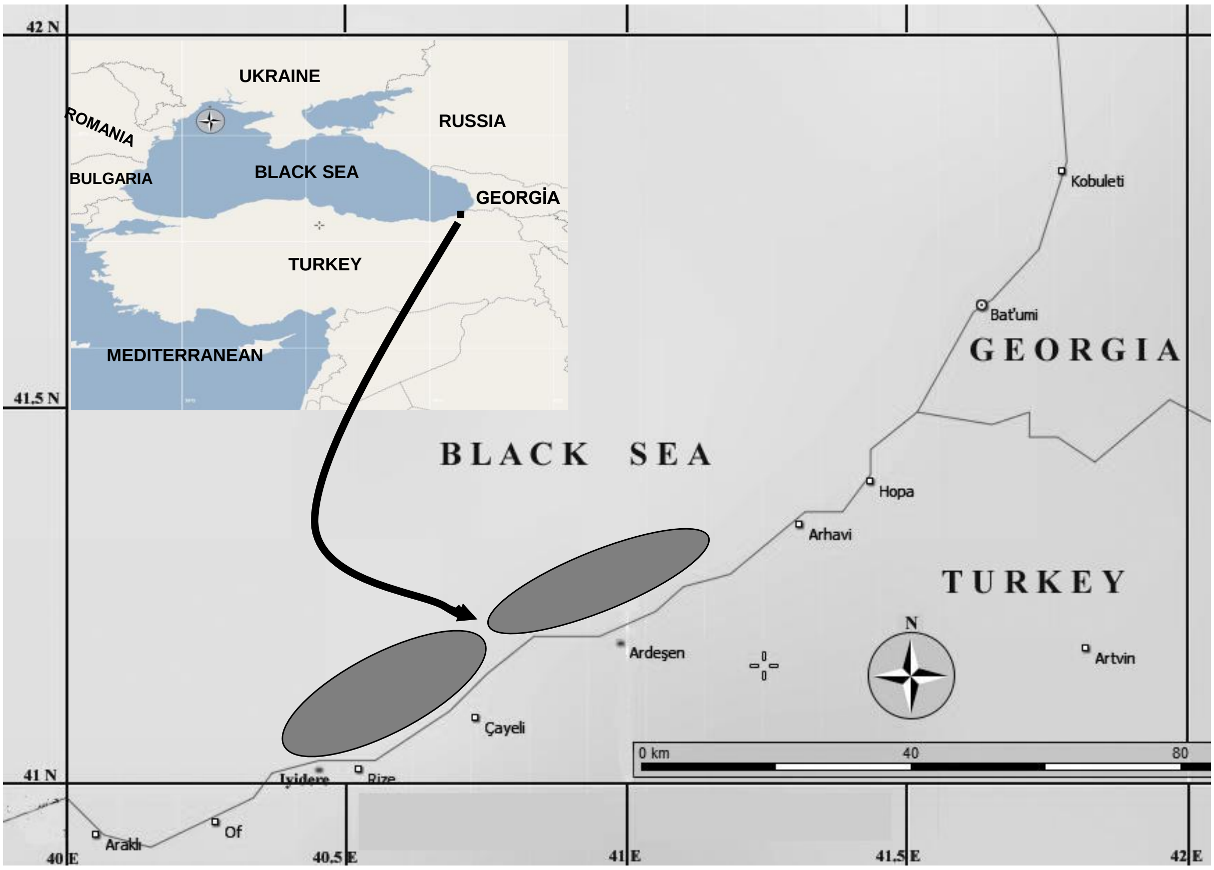

Figure 1. Sampling area of thornback ray (*Raja clavata*) around the Rize province in the south-east Black Sea, Turkey

Maturity and spawning period

The maturity stages of examined thornback ray specimens were assigned according to the maturity scale proposed by both Serra-Pereira et al. (2011) and Saglam and Ak (2011): stage (1) immature, stage (2) maturing, stage (3) mature, and/or actively-post spawning.

The spawning period was graphically determined for both sexes by the seasonal variation of the mean values of the gonadosomatic index (*GSI*) as:

$$\mathrm{GSI} = \frac{Wg}{W} \times 100\,,$$

where W_g is gonad weight (g), W is the total thornback ray weight (g).

Size at sexual maturity (L_m)

Size at sexual maturity was determined from both sexes of thornback ray by calculating the proportion of mature specimens in 5 cm size classes. Individuals with stage 2 and 3 were considered as mature (Serra-Pereira et al., 2011; Saglam and Ak, 2011). The proportion of mature female and male by size were fitted to the logistic equation:

$$P = \frac{1}{1 + e^{a+bL}}\,,$$

where, P is the proportion of mature specimens, a and b are the coefficients of the equation, and L is the total length. Size at sexual maturity (L_m), corresponding to 50% sexually mature for specimens, was calculated from - (a/b).

Length at maximum yield per recruit (L_{opt})

Length at maximum yield per recruit for both sexes of thornback ray was calculated from the following empirical equation suggested by Froese and Binohlan (2000).

$\log L_{opt} = 1.053 \times \log(L_m) - 0.0565$,

where, L_m is the size at sexual maturity (or the length at which 50% of a population become sexually mature for the first time).

RESULTS

A total of 265 (160 female and 105 male) specimens of thornback ray were examined. The total length ranged 13.1 and 95.9 cm (mean 73.06 ± 1.568 cm) for females and between 12.5 and 99.2 cm (mean 67.9 ± 2.07 cm) for males. Size frequency distribution between sexes were significantly different (Kolmogorov-Smirnov two-sample test; d = 0.197, $P < 0.05$). Female mean total length was significantly (t-test, $P < 0.05$) greater than the corresponding one for males.

Spawning period

The gonadosomatic index (GSI) values varied between 0.93 (winter) and 0.95 (spring) for both sexes (Fig. 2). The difference between the mean seasonal GSI values of female and male were not significantly different (ANOVA, P > 0.05). The GSI analysis revealed that thornback ray showed reproductive activities throughout the year.

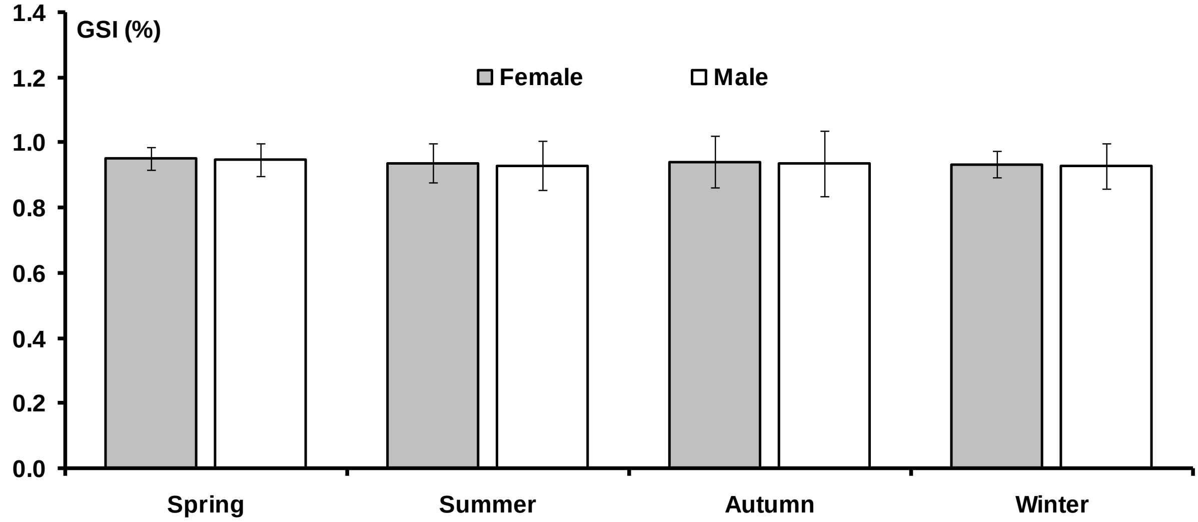

Figure 2. Seasonal variation of the gonadosomatic index (GSI) of thornback ray (*Raja clavata*) around the Rize province in the south-east Black Sea. Vertical bars indicate the standard error

Size at maturity (L_m)

Total length of female ranged between 13.1 and 75.0 cm (n = 37) in stage I (immature), between 71.0 and 88.1 cm (n = 8) in stage II, between 67.0 and 95.9 cm (n = 115) in stage III. When it comes to males, total length ranged between 15.5 and 68.3 cm (n = 33) in stage I (immature), between 61.0 and 82.5 cm (n = 18) in stage II, between 66.0 and 99.2 cm (n = 54) in stage III.

Size at sexual maturity was estimated from 265 thornback ray of which 195 were mature (Fig. 3). The relationship between total length and the proportion of mature females was:

$$P = \frac{1}{1+e^{14.447-0.1915*TL}} \text{ and for males it was: } P = \frac{1}{1+e^{13.955-0.1946*TL}},$$

from this, the estimated size for 50% sexual maturity (TL_{50}) was 75.44 cm for females and 71.71 cm for males (Fig. 3).

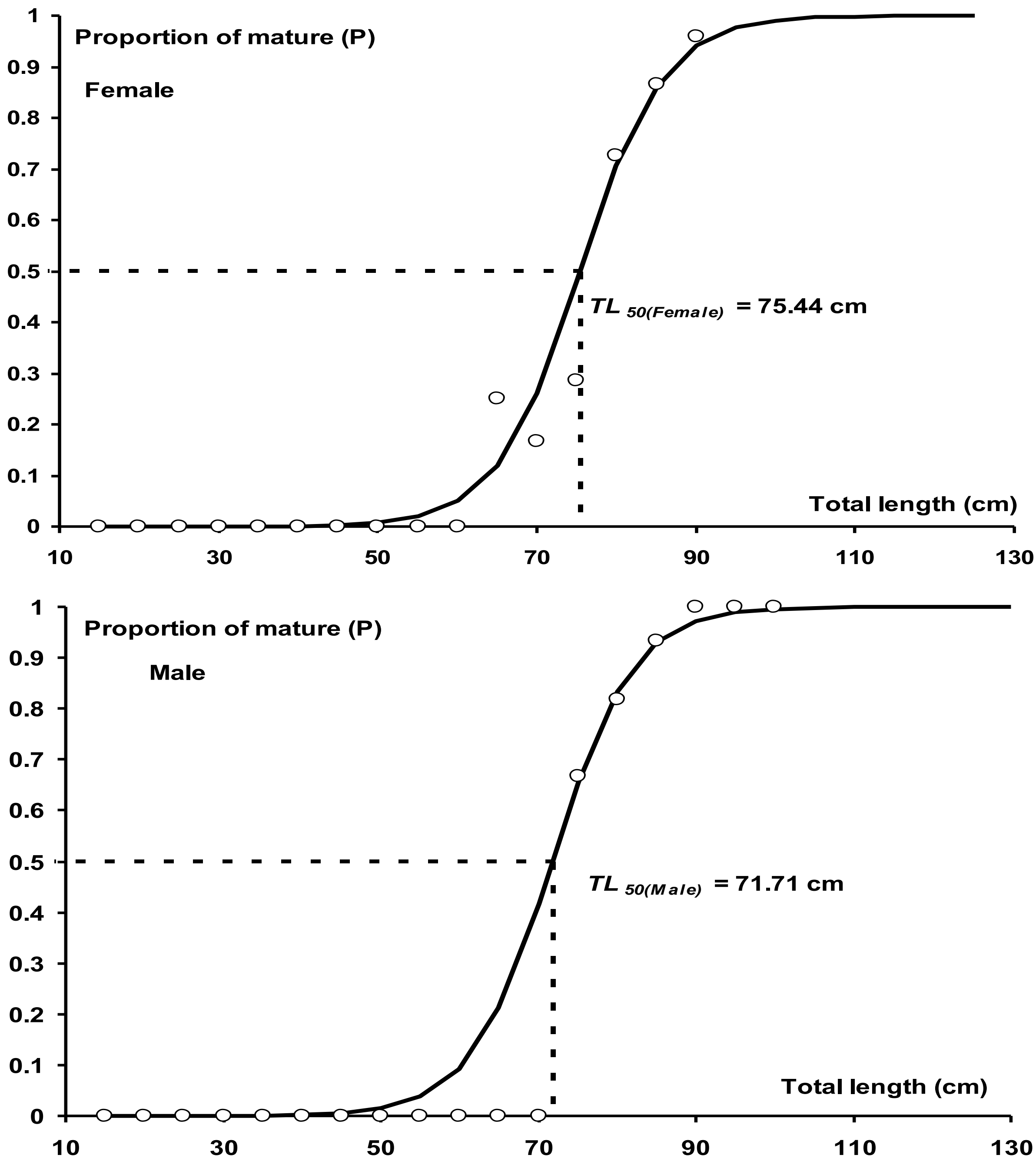

Figure 3. Logistic function fitting the proportion of mature female and male with total length (cm). TL_{50} corresponding to proportion of 50% of mature specimens

Length at maximum yield per recruit (L_{opt})

The L_{opt} was estimated from the empirical relationships between length at maximum yield per recruit and size at maturity. Thus, L_{opt} was estimated as 83.3 cm for females and 79.0 cm for males, and also L_{opt} was larger than L_m for both sexes of thornback ray.

DISCUSSION

Spawning period

In the latest study, spawning period of the Mediterranean marine fish species except Black Sea fish was reviewed by Tsikliras et al. (2010) and were classified in two main groups as cold (October, November, December, January, February, March, April), and warm (May, June, July, August, September) months. A small percentage (5.1%: 26 stocks including 13 species) of the Mediterranean fish stocks were also reported as all year-round spawner. However, thornback ray data were never presented in the review. It was described firstly as an all year round spawner in British waters by Holden (1975). Later, continuous spawning was reported from the southern North Sea (Pawson and Vince, 1999) off the coast of Languedoc, southern France, northern Mediterranean (Capapé et al. 2007) and of the Trabzon province, the southeastern Black Sea, Turkey (Saglam and Ak, 2011). Similar to previous studies, all year round spawning feature for thornback ray has been proven and/or redefined from the present study in the Black Sea. Continuous spawning was also reported for other rajid species such as eyespot skate, *Atlantoraja cyclophora* (Regan, 1903) (Oddone and Vooren, 2005), and spotted ray, *Raja montagui* Fowler, 1910 (Walker, 1999). Contrary to the aforementioned results, thornback ray did not report as a continuous spawner in the north (Matosinhos) and the center (Peniche) of Portugal (Serra-Pereira et al., 2011) and in the Gulf of Gabès (south-central Mediterranean) (Kadri et al., 2014). Although there is an evidence that the duration of the spawning period may vary both annually and geographically, it was suggested that length of daylight is the main factor controlling the ovarian cycle and that temperature controls the rate of egg laying (Holden, 1975). Holden et al. (1971) demonstrated that the rate and peaks of egg deposition in different ray species such as thornback ray, blonde ray (*Raja brachyura* Lafont, 1871), and spotted ray were dependent on water temperature fluctuations. As can be seen from the above explanations, the spawning period of thornback ray may vary according to the region and years in the Mediterranean Sea (Capapé et al. 2007; Kadri et al., 2014), but this event has not yet been proven for the stock of the Black Sea and the North Sea.

Length at maximum yield per recruit (L_{opt})

The L_{opt} is an important fishery management parameter, because it is obtained at an intermediate age t_{opt} where the result of the number of surviving individuals multiplied by their average weight results in the highest biomass, usually correspondes to the highest egg production and also it can be a useful tool in defining routine fisheries management measures such as minimum size limits, closed seasons, etc. (Holt, 1958; Gulland. 1983; Frose and Binohland, 2000). However, estimation of L_{opt} requires knowledge of basic population parameters as natural mortality (M) and the von Bertalanffy growth function parameter, K. This two parameters are not easily obtained. Therefore, an empirical relationship ($\log L_{opt}$ = 1.053*$\log L_m$ - 0.0565) was reported between L_{opt} and L_m to provide an estimation of this parameter (Frose and Binohland, 2000). In the previous studies reported on thornback ray, L_m values were assembled and L_{opt} values calculated using the proposed formula, and the results were shown in table 1. The outcomes of previous studies which are conducted in different geographical areas showed that the L_{opt} ranged between 64.1 and 81.0 cm (mean 70.7 ± 1.4 cm) for males and between 64.9 and 101.5 cm (mean 79.0 ± 2.7 cm) for females (Table 1). Moreover, the L_{opt} values for females were greater than males and L_{opt} values were greater than L_m for both sexes of thornback ray (Table 1). In the present study, similar results were found for both sexes of thornback ray stocks in the Black Sea. Besides, when using the recommended empirical formula for calculation L_{opt} from L_m, the calculated L_{opt} value may be smaller than to L_m in small fish species, whereas in large fish species (slow-growing species) L_{opt} is usually larger than L_m (Froese and Binohlan, 2000). E.g. for small L_m values (e.g. L_m = 10.5 cm), L_{opt} is a lower value (10.4 cm) than $L_{m,}$ and also for higher L_m values (e.g. L_m = 90 cm), L_{opt} is a higher value (100.3 cm) than L_m. Thus, thornback ray is a slow-growing and long-lived fish species (Ryland and Ajayi, 1984), it may be considered normal that L_{opt} values are higher than L_m values for both sexes of thornback ray stock in the Black Sea.

Reproductive load (L_m/L_{max})

L_m/L_{max} ratio can be used to compare potential trends in maturation and energetic investment in reproduction and/or growth for fish species (Tsikliras and Stergious, 2014) and also express the proportion of the potential growth span of the species before maturation (Beverton 1963), so this ratio was calculated to compare and/or to express the reproductive load from different stock in different geographical areas for thornback ray (Table 1). The results of previous studies which are conducted in different geographical areas and/or different latitude showed that the L_m/L_{max} ratio of thornback ray ranged between 61.1 and 80.9 (mean 69.9 ± 1.5) for males and between 69.0 and 88.9 (mean 75.3 ± 2.1) for females (Table 1). Moreover, the L_m/L_{max} ratio of different species such as Mediterranean starry ray *Raja asterias* Delaroche, 1809, longnose skate *Beringraja rhina* (Jordan & Gilbert, 1880), brown ray *Raja miraletus* Linnaeus, 1758, undulate ray *Raja undulata* Lacepède, 1802 belonging to Rajidae family ranged between 0.74 and 0.88 for males and between 0.83 and 0.90 for females in the Mediterranean (Tsikliras and Stergious, 2014). These results showed that L_m/L_{max} ratio of females was generally larger than males. In the present study, similar results were found for thornback ray stocks in the Black Sea. Moreover, L_m/L_{max} ratio may vary within and between different species due to many factors such as sampling strategy (e.g. sampling depth), latitude variation (depending on water temperature) and nutritional quality or availability of food, etc. (Capapé, 1976; Longhurst and Pauly, 1987; Abookire and Macewicz, 2003; Trip et al., 2014; Tsikliras and Stergious, 2014).

Size at maturity (L_m)

Size at maturity is an important fisheries management parameter because it is the basis in setting the minimum landing size (MLS) of exploited fish stocks, i.e. the minimum legal size under which fish should not be caught (Tsikliras and Stergiou, 2014). The results of previous studies which are conducted in different geographical areas showed that the L_m values of thornback ray ranged between 58.8 and 73.5 cm (mean 64.6±1.2 cm) for males and between 59.5 and 91.0 cm (mean 71.7±2.3 cm) for females (Table 1). According to the previous results, L_m values of females were calculated to be larger than males in 13 studies except for two studies (Jardas, 1973; Ryland and Ajayi, 1984) for thornback ray (Table 1).

In the Black Sea, L_m value for thornback ray was previously reported as 66.7 cm for females and 64.0 cm for males (individuals collected using longline near the Georgian border at depths between 20 and 120 m in 2002 - 2003 and TL of samples was between 34.3 cm and 95 cm) (Demirhan et al., 2005). Later, L_m values were reported as 74.6 cm for females and 71.8 cm for males (individuals collected using bottom trawl off the coast of Trabzon province at 20 - 40 m depth in 2009 and TL was between 15.6 - 93 cm for females and between 14.3 - 92 cm for males) (Saglam and Ak, 2011). The L_m results of our study were larger than the study of Demirhan et al. (2005) but close to the study of Saglam and Ak (2011). These differences between the studies are most probably due to different length composition used to size at maturity calculation, different sampling methods, a different environmental condition such as temperature, and different fishing pressure levels among the years.

Thornback ray stocks are not under overexploitation in the eastern Black Sea and this species is caught only as by catch during the turbot gill nets fisheries and by catch, individuals are released back to the sea as alive or dead (personal observations). Maturity sizes of thornback ray obtained in the Black Sea are relatively larger than the reported in other regions (see Table 1). This variability may be most probably due to differences in fishing pressure and also differences in biotic and abiotic factors. It is reported that fishing pressure was brought about a reduction in the maturity size of thornback ray in the Solway Firth (Nottage and Perkins, 1983).

Size at maturity is a good predictor of vulnerability to fishing, especially for species maturing at larger-sized fish species (i.e., ≥ 25 cm and ≥ 3 years) such as thornback ray (Anderson et al. 2008; Tsikliras and Stergiou, 2014). Moreover, the overexploitation of small and/or immature individuals may have harmful consequences for recruitment and stock conservation. Thus, MLS should always exceed L_m regardless of species and stocks (Döring and Egelkraut 2008; Tsikliras and Stergiou, 2014). Thornback ray is not amongst commercially important fish species and no MLS limits are defined for the catch in the Black Sea. The results of the present study could be used as a biological input parameter regarded as a reference (e.g., the MLS: between 67 - 78 cm total length) for management of Black Sea stocks of this species. The MLS's have been implemented as 40 cm disc width for ray species in the Southern and the Kent and Essex Sea Fisheries Districts of the UK by Sea Fisheries Committees (Ellis, 2016).

Table 1. Comparison of maximum total length (L_{max} in cm), length at maximum yield per recruit (L_{opt} in cm), size at maturity, (L_m/L_{max} in %) of thornback ray (*Raja clavata*) in southeast Black Sea with previous study results in different geographical reg

Male				Female				Area
L_{max}	L_{opt} **	L_m	L_m/L_{max}	L_{max}	L_{opt} **	L_m	L_m/L_{max}	
107.4*	81.0	73.5	70.4	135.0*	101.5	91.0	71.2	British water, English Channel, UK
99.0	66.0	60.5	61.1	85.2*	64.9	59.5	69.6	British Isles, Camarthen Bay, UK
94.0	72.9	66.5	70.7	98.0	82.9	75.1	76.6	British Isles, UK
89.2*	67.7	62.0	69.7	93.9*	71.2	65.0	69.9	Irish Sea, Solway Firth
90.0	72.0	65.7	73.0	104.0	79.1	71.8	69.0	Irish Sea
95.0	64.1	58.8	61.9	77.8	77.6	70.5	90.6	Irish Sea, Caernarfon Bay
73.3	64.6	59.3	80.9	95.0	66.8	61.2	64.4	Adriatic Sea, Croatia
93.6*	71.0	64.8	69.9	91.6*	69.5	63.5	69.8	Adriatic Sea
105.0	74.2	67.6	64.4	96.5	86.7	78.4	81.2	Atlantic, Portuguese
89.0	71.2	65.0	73.0	104.0	87.4	79.0	76.0	Mediterranean Sea, Tunisia
85.0	65.3	59.9	70.5	85.0	83.5	75.6	88.9	Mediterranean Sea, France
95.0	70.0	64.0	67.4	88.2	73.2	66.7	75.6	Black Sea, Turkey
92.0	79.1	71.8	78.0	93.0	82.3	74.6	80.2	Black Sea, Turkey
$\bar{X}$±SE	**70.7±1.4**	**64.6±1.2**	**69.9±1.5**		**79.0±2.7**	**71.7±2.3**	**75.3±2.1**	

(*): calculated from $L_{max} = (L_m - 5.541) / 0.633$ (Tsikliras and Stergiou, 2014), (**): calculated from $\log L_{opt} = 1.053 \times \log(L_m) - 0.0565$ (Binohlan and Froese, 2

Acknowledgements: We thank Sami Akmermer, Kazım Akmermer, Uğur Akmermer and Ahmet Kalkavan for their help during the field studies. We would like to thank two anonymous reviewers for their helpful comments. This study was supported by Recep Tayyip Erdoğan University with project numbers 2013.103.03.1 and 2010.103.02.

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